

Satellite Observations of Aerosol Indirect Effects over the Indian Ocean

Second International Conference on Global Warming and the Next Ice Age, Aerosol Workshop on Climate Prediction Uncertainties

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Outline of Talk



The Moderate Resolution Imaging Spectroradiometer (MODIS) experiment measures

**Visible and Infrared Radiances
and retrieves**

**Cloud top pressure and temperature
Aerosol optical depths**

**Quantify aerosol indirect effects as a function of
cloud particle type (i.e. liquid droplets and ice crystals)**

Data Used in this Study



Focus on February – March 2003 - 2005 time frame

MODIS “joint product” 1.38 μm cirrus reflectance data

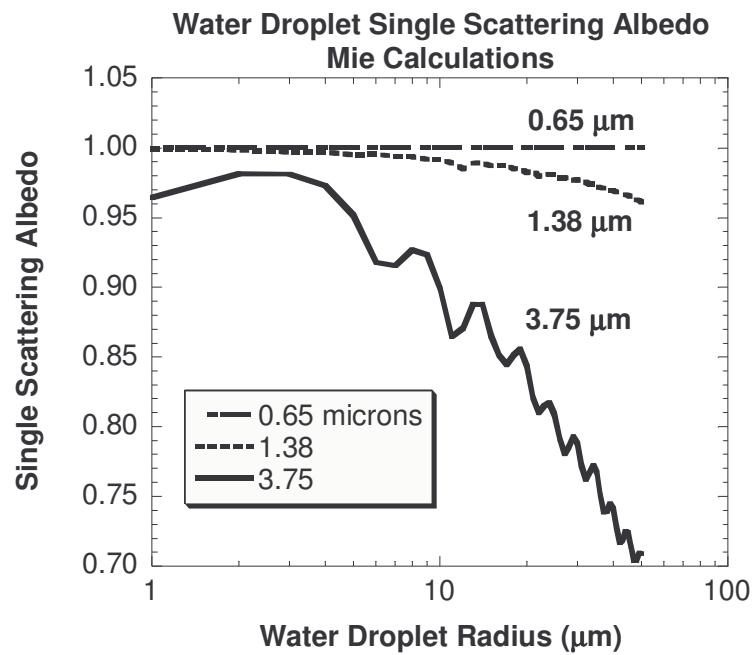
MODIS 3.75 μm cloud reflectance data
- derived from MODIS radiances

Number of Data Elements				
<u>P (hPa)</u>	<u>T (C)</u>	<u>Phase</u>	<u>Ocean</u>	<u>Land</u>
251 - 158	-49	ice	21417	805
398 - 251	-29	ice	18840	3987
630 - 398	-9	liquid	7106	2849
900 - 630	9	liquid	13503	3817

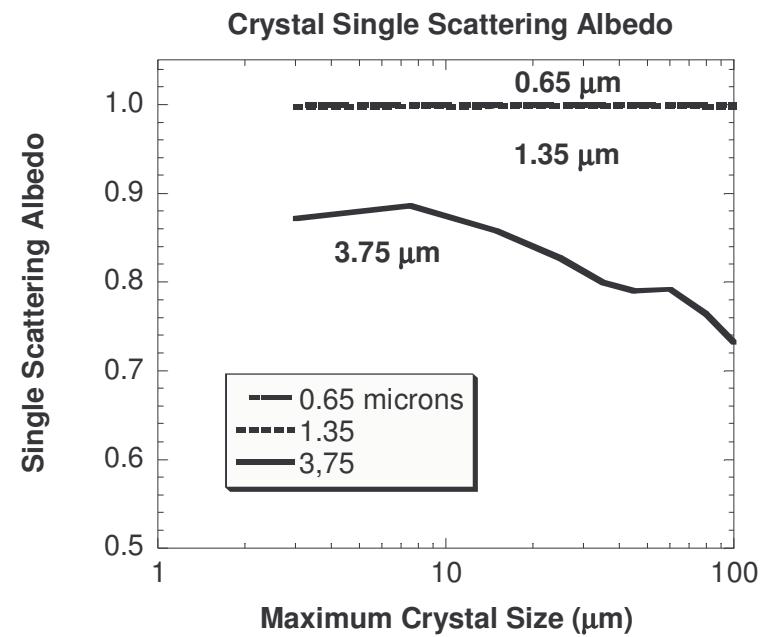
Analyze observations in aerosol optical depth bins
0 – 0.15, 0.15 – 0.30, 0.30 – 0.50
for cloud optical depths between 4 and 10

Single Scattering Albedo, ω

Water Droplets



Ice Crystals



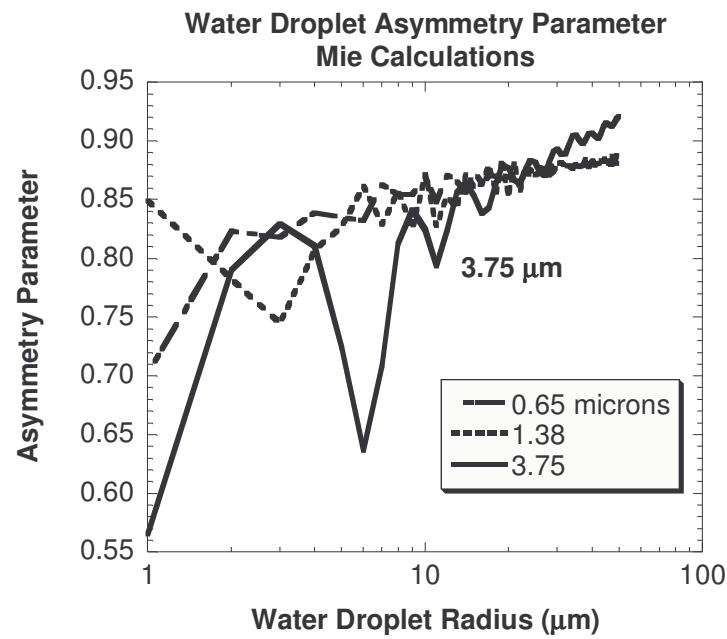
Derivatives $d\omega / dr$ are largest at 3.75 microns

Larger ω corresponds to more reflective clouds

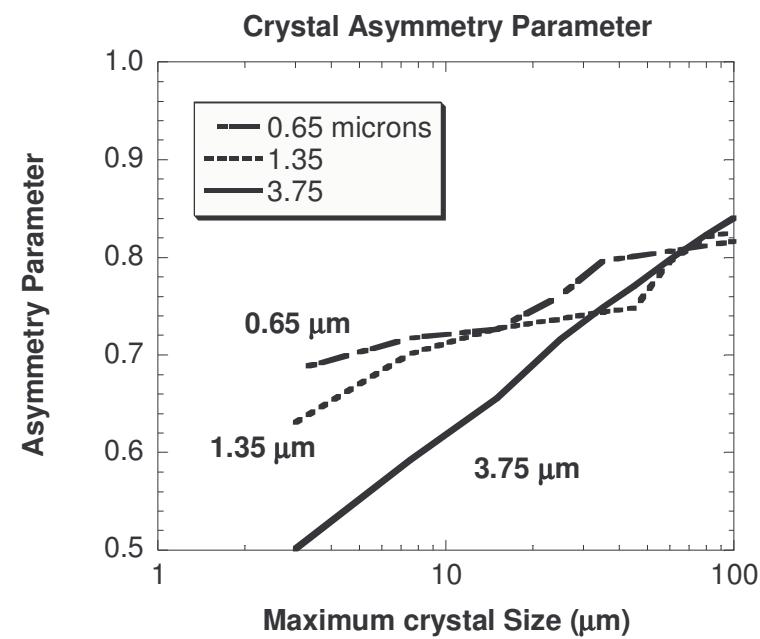
Asymmetry Parameter, g



Water Droplets



Ice Crystals



Derivatives dg / dr are largest at 3.75 microns

Lower g corresponds to more backward scattering
(i.e. larger cloud reflectivity).

Rosenfeld-Lensky Methodology



Intensity I at $3.8 \mu\text{m}$ at the top of the atmosphere is due to two terms:

- 1) Reflected sunlight F bounced off of the cloud top
- 2) Emission from the cloud top

t_1 transmission factor from sun to cloud, and back to satellite calculated by using 10.8 and $12 \mu\text{m}$ brightness temperature difference

t_2 transmission factor from top of cloud to satellite ~ 1

$$I(3.8 \mu\text{m}) = t_1 (F \mu_0 / \pi) R(3.8 \mu\text{m}) + t_2 B(T, 3.8 \mu\text{m}) [1 - R(3.8 \mu\text{m})]$$

Cloud reflectivity R at $3.7 \mu\text{m}$ is then

$$R(3.8 \mu\text{m}) = [I(3.8 \mu\text{m}) - t_2 B(T, 3.8 \mu\text{m})] / [t_1 (F \mu_0 / \pi) - t_2 B(T, 3.8 \mu\text{m})]$$

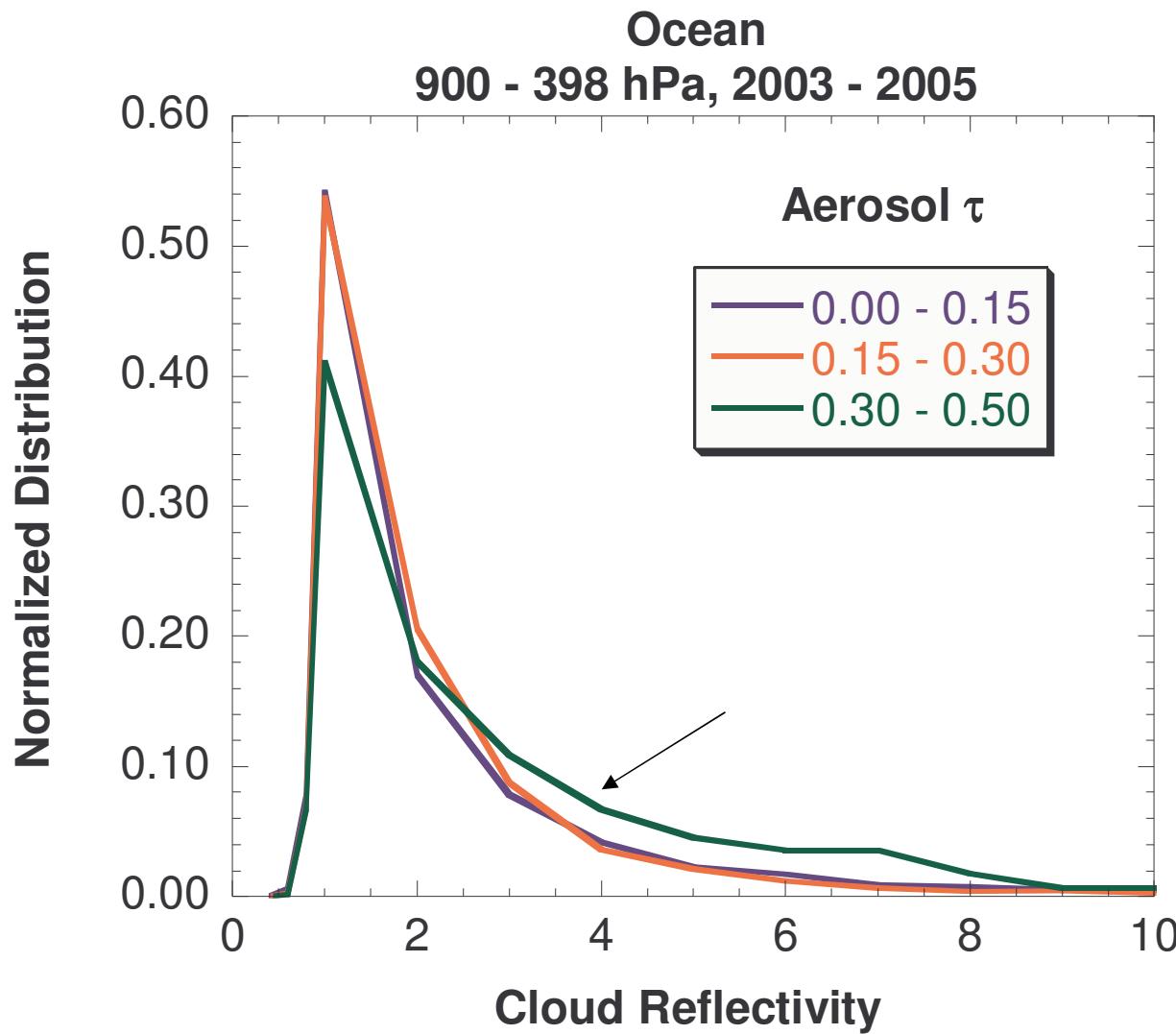
Obtain temperature T of cloud top from $12 \mu\text{m}$ radiances

Only calculate cloud reflectivity if visible reflectance $> 40\%$

See Rosenfeld and Lensky, Am Met Soc Bull, v79, Nov 1998.

MODIS Probability Distribution Functions at 1.38 μm

Water droplets

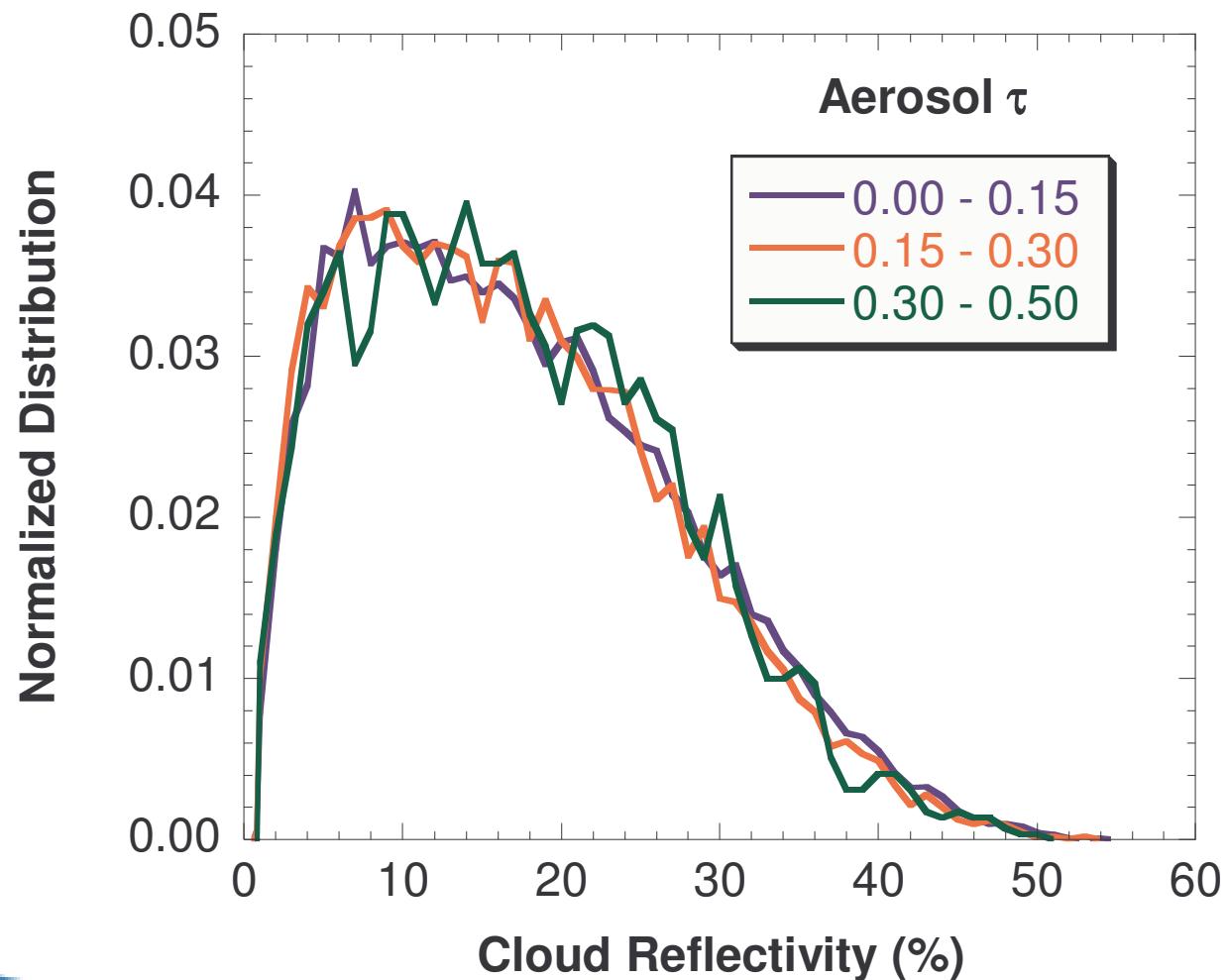


pdf
shift in tail
is seen

MODIS Probability Distribution Functions at 1.38 μm Ice crystals

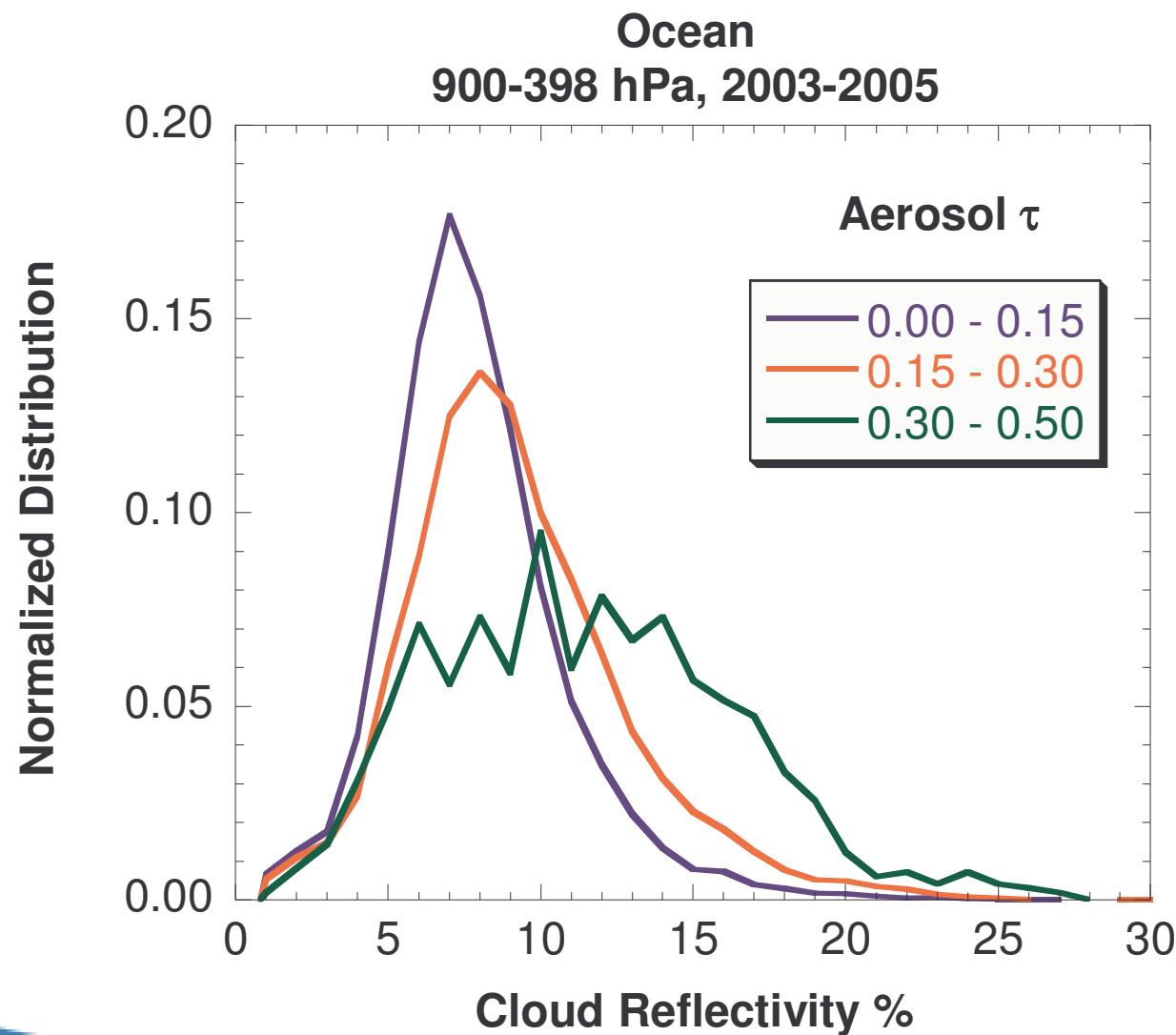


Ocean
398 - 158 hPa, 2003 - 2005



pdf
shifts
not seen

MODIS Probability Distribution Functions at 3.75 μm Water droplets

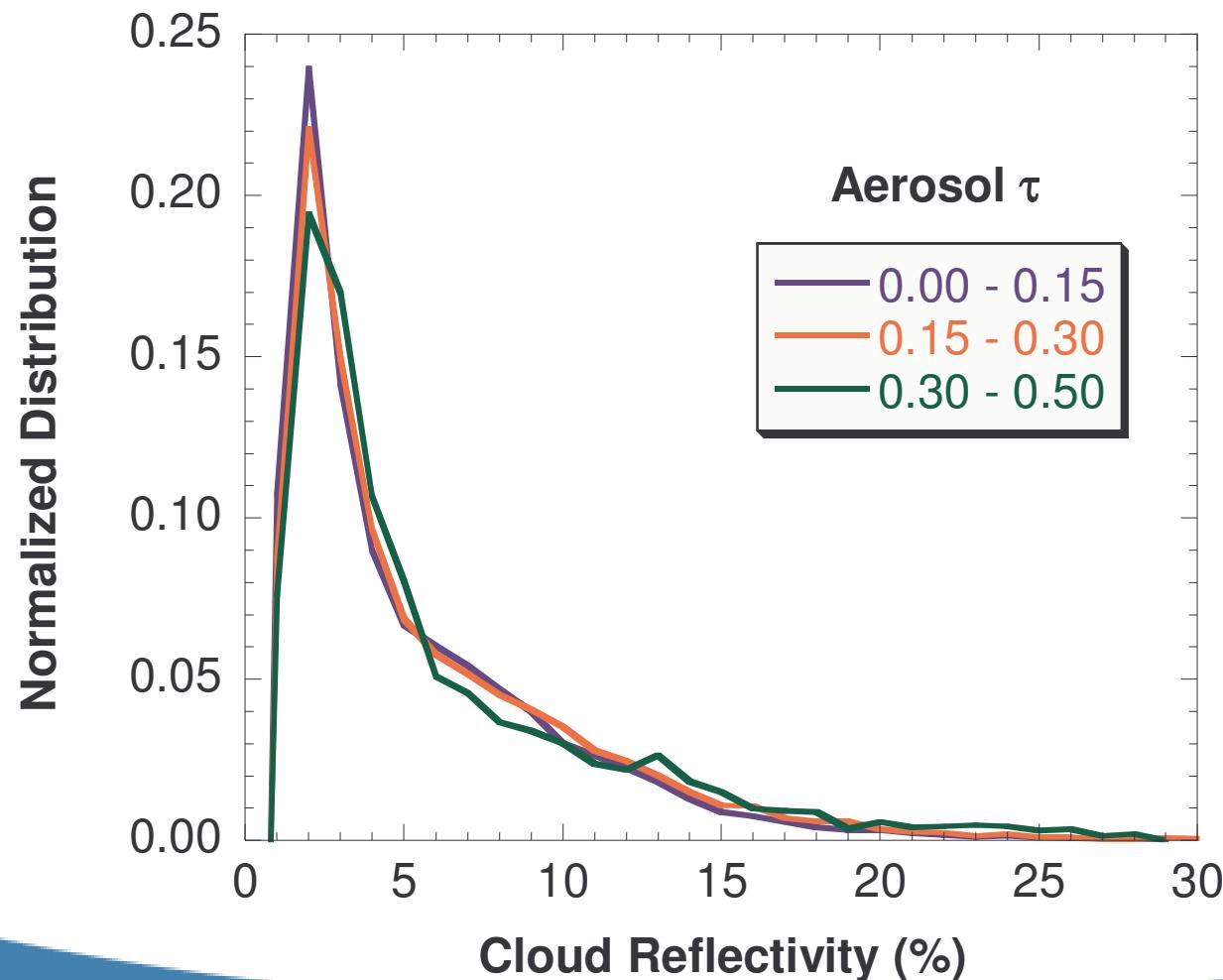


pdf
shifts
are seen

MODIS Probability Distribution Functions at 3.75 μm Ice crystals



Ocean
398 - 158 hPa, 2003-2005



pdf
shifts
not seen

Theoretical Calculations



DISORT – discrete ordinates program

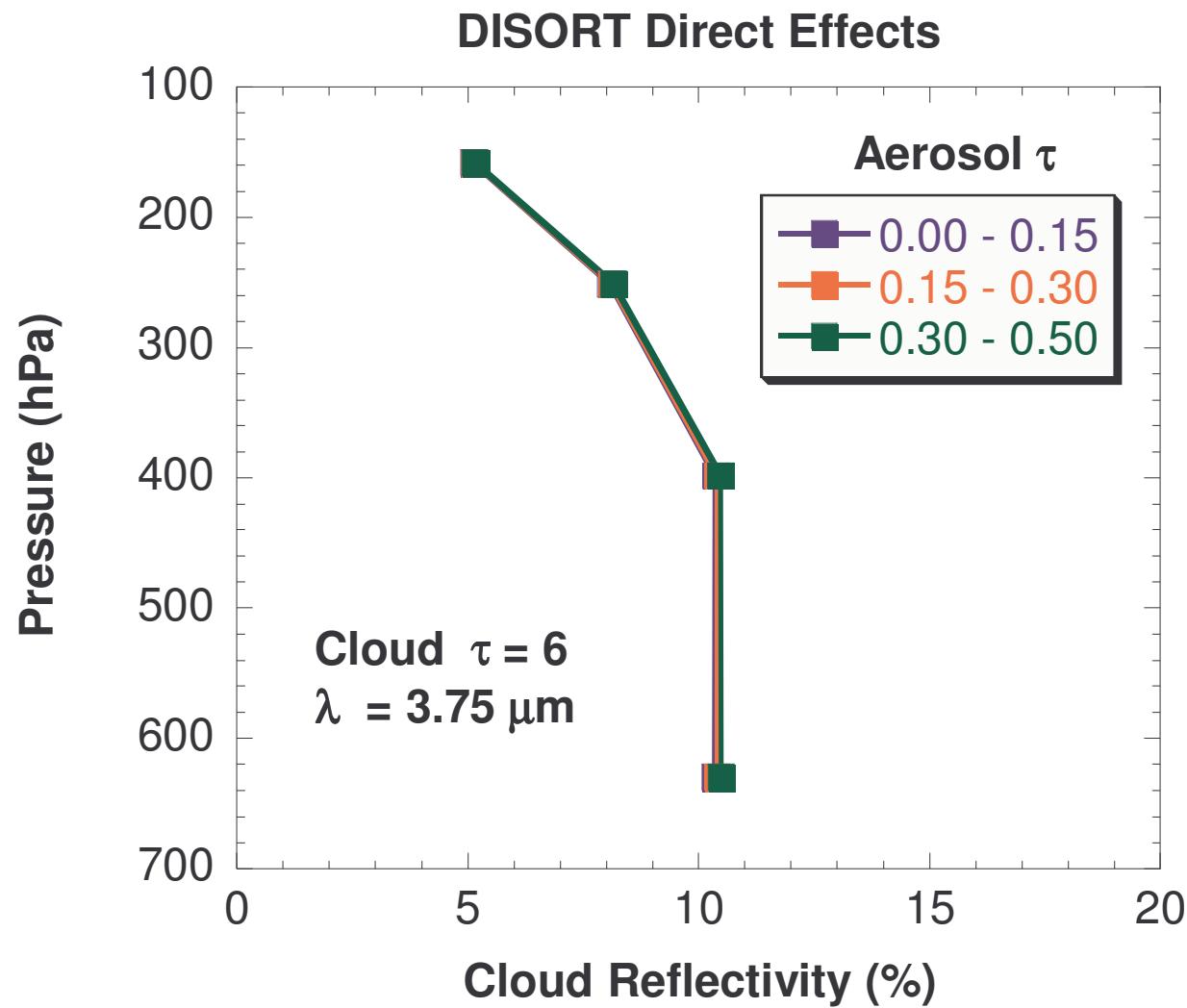
Plane parallel, multiple scattering

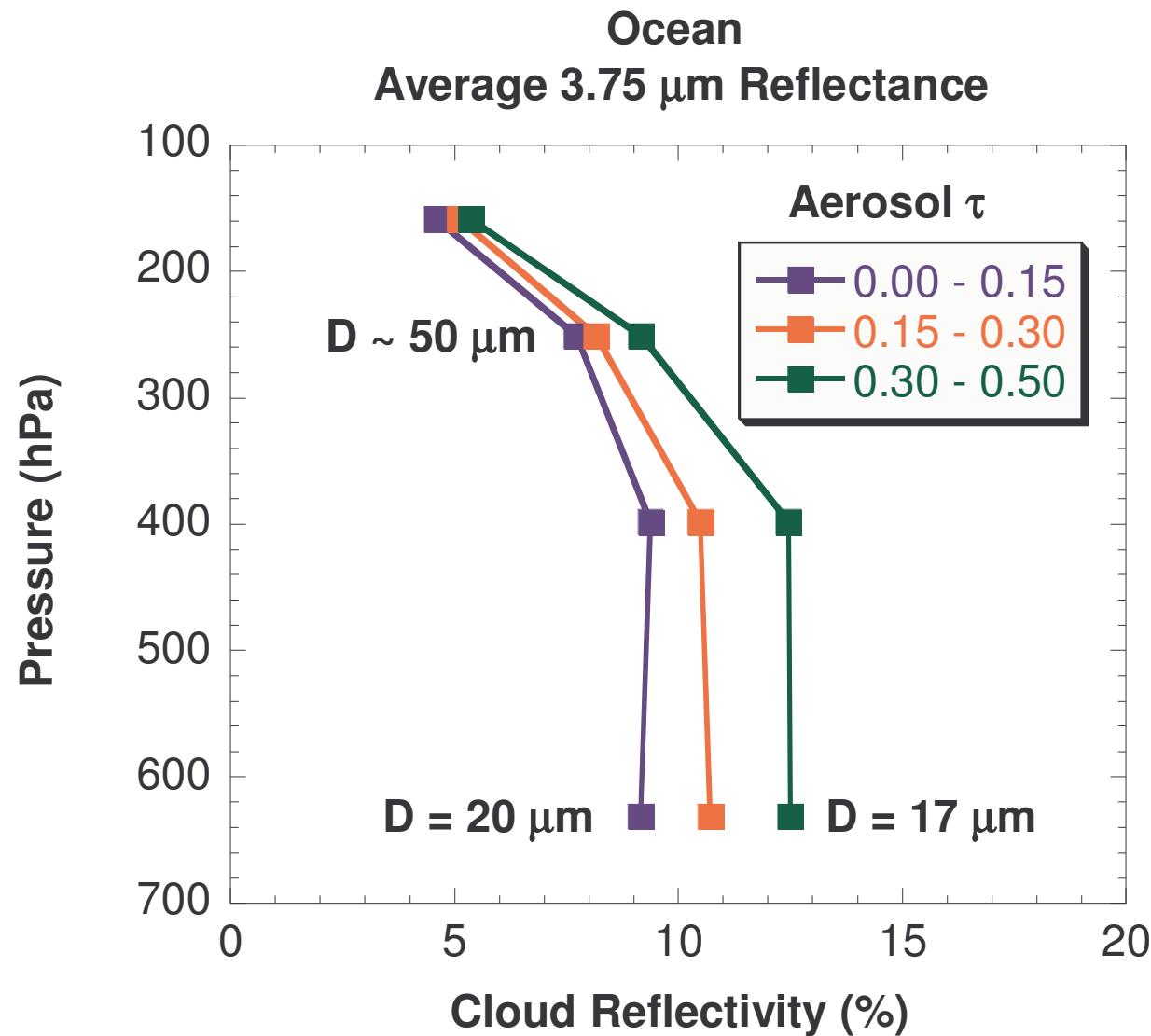
**Specify max diameters D in four pressure bands
(900-630, 630-398, 398-251, 251-158 hPa)**

**Calculate cases for total cloud optical depth $\tau_c=6$
distributed uniformly for the pressure ranges
(900-630, 900-398, 900-251, 900-158 hPa)**

**D determines the cloud asymmetry parameter (g)
and single scattering albedo (ω) values**

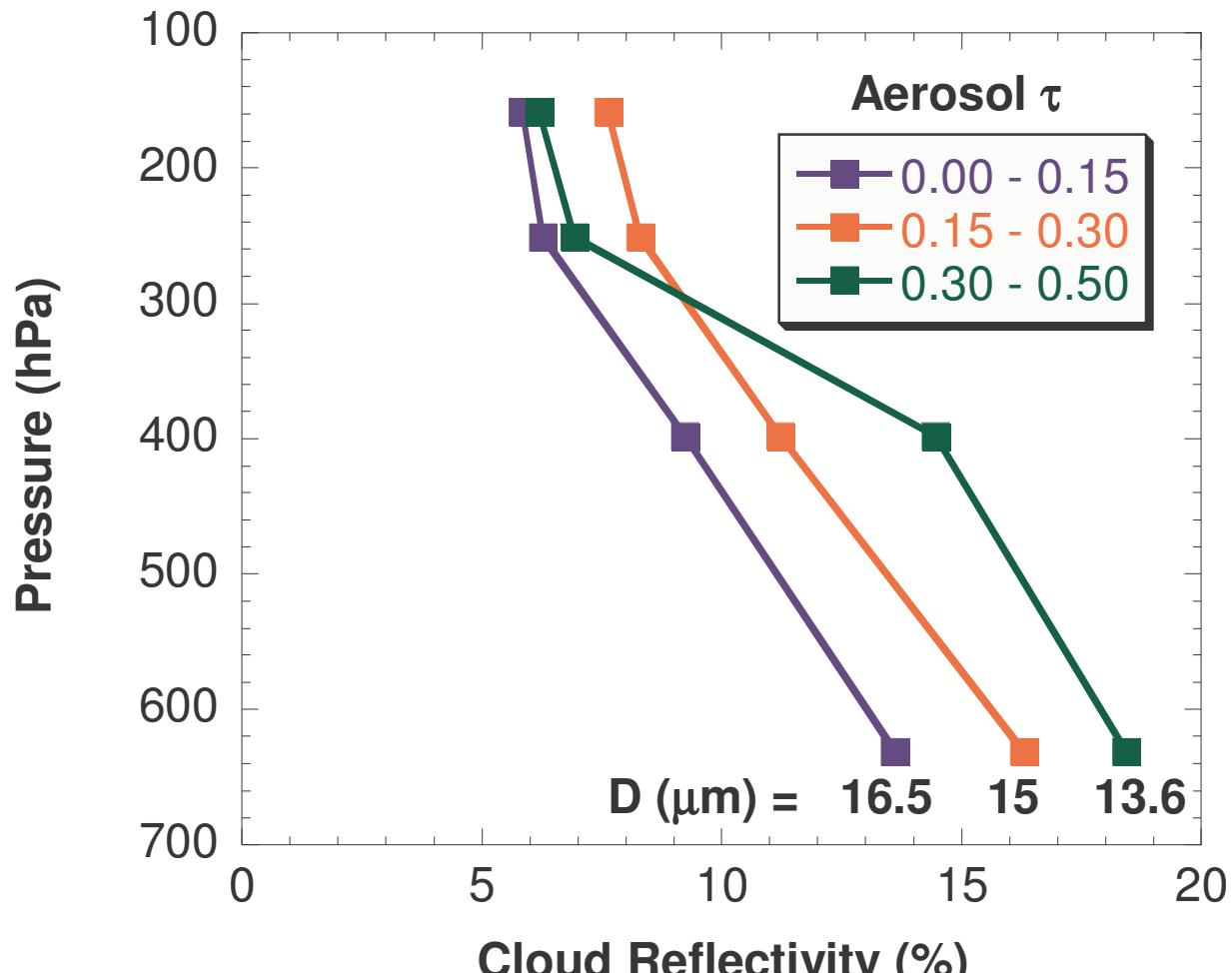
Fixed diameters, aerosol τ is varied





Comparison: POLDER data offshore of India, D \sim 20 μm
Numbers by curves are particle diameters

Land
Average 3.75 μm Reflectance



Comparison: POLDER data over India, $D \sim 14 - 18 \mu\text{m}$
Numbers by curves are particle diameters



Measure of Indirect Effects

Feingold, First measurements of the Twomey aerosol indirect effect using ground-based remote sensors, GRL, v30(6), 1287, doi:10.1029/2002GL016633, 2003.

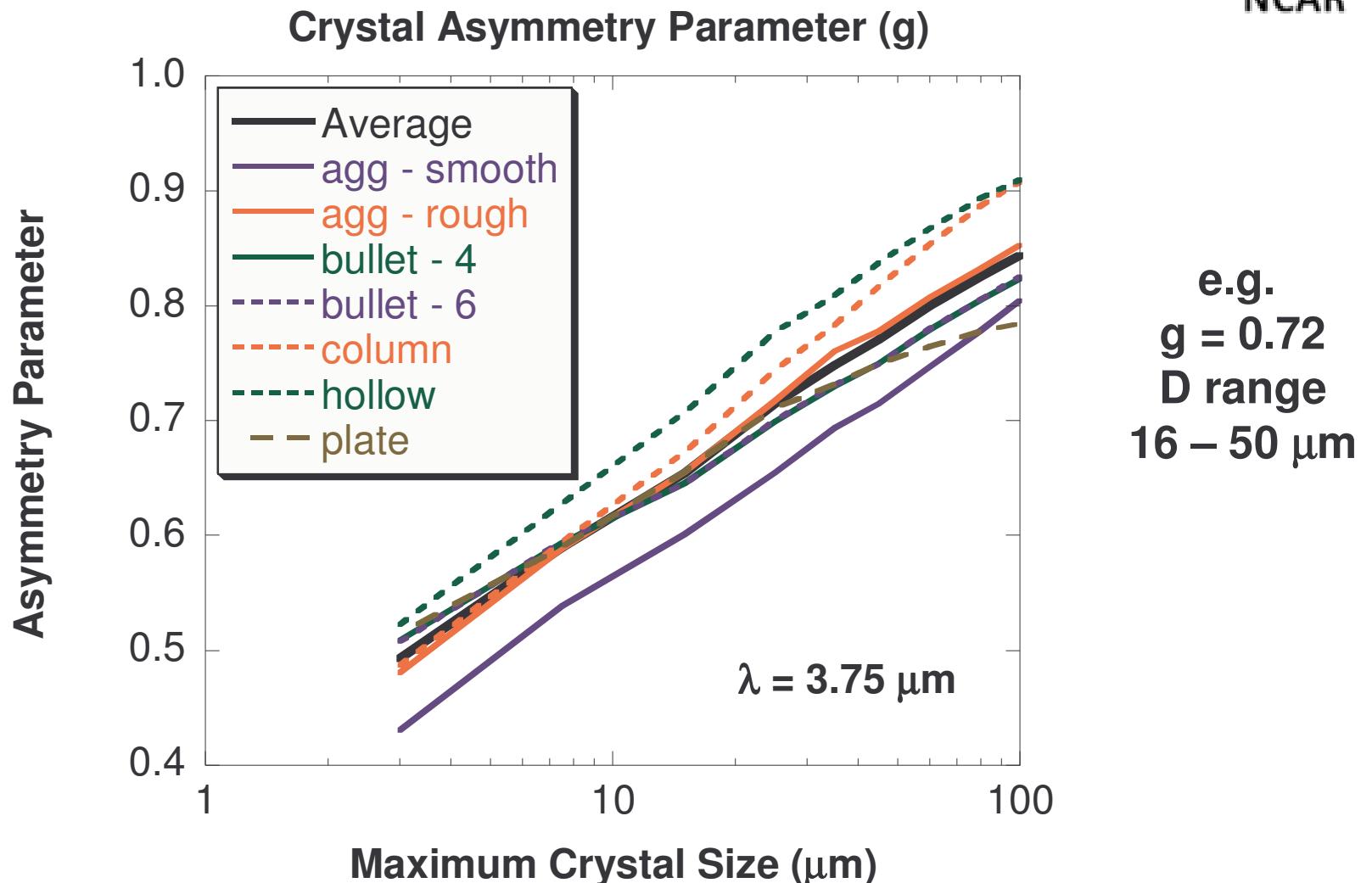
$$IE = - \partial (\ln r_e) / \partial (\ln \alpha)$$

r_e the effective cloud droplet radius, μm
 α aerosol extinction (km^{-1}) coefficient

Kansas ARM site data, $IE \sim 0.07$ to 0.11

MODIS satellite data for lower troposphere
land $IE \sim 0.11$

Sensitivity to Particle Shape



Based upon Wyser and Wang, J. Atmos. Res., 49, 315, 1998

Measurements of Indirect Effects



Chylek et al., Aerosol indirect effect over the Indian Ocean, *GRL*, v33, 2006.

Analyzed MODIS monthly averaged archived data products, 60 – 95 E and 15 -25 N

**Clean air (Septembers 2000 – 2004)
Polluted air (Januarys 2001 – 2005)**

As aerosol increases, see
- smaller cloud droplets
- larger ice crystals

**Kruger, Marks, and Graßl, Influence of pollution
on cloud reflectance, JGR, v109, D24210,
doi:10.1029/2004JD004625, 2004.**

Analyzed AVHRR reflectance data

**Central Europe SO₂ decreased by 50% from
1985 to 1999.**

**Stratus cloud reflectance 13% larger 1981-1984
versus 1981-1999**

Cumulus reflectance 6% larger for 1981-1984

Conclusions



Cloud reflectance derivatives $dR / d(\text{aerosol } \tau)$ due to aerosol indirect effects are larger at $3.75 \mu\text{m}$ than at 1.38 or $0.65 \mu\text{m}$

Probability distribution functions of $3.75 \mu\text{m}$ reflectance have “resolved” peaks – aerosol indirect effects are discernable

Aerosol indirect effects are consistently seen over the ocean at pressure levels associated with liquid droplets

At pressure levels associated with ice crystals, aerosol indirect effects are (surprisingly) not present.